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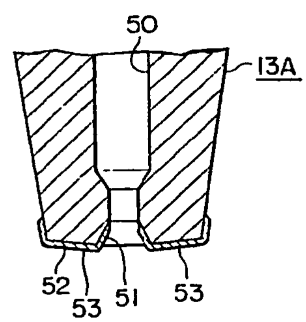
(54) Method and apparatus for wire bonding

(57) A wire bonding apparatus, such as used frequently for assembling electronic parts, is designed to prevent a physicochemical reaction, which leads to defects in a wire bonding operation, from occurring between a bonding wire and a wire connecting tool so that fusion of the bonding wire to the wire connecting tool does not occur. The material of the connecting tool 13A is a substance which does not easily generate a physicochemical reaction with the bonding wire, and covering at least the region of the wire connecting tool 13A which contacts the bonding wire is a film 53 of a material which does not easily generate a physicochemical reaction with the bonding wire.

FIG. 9



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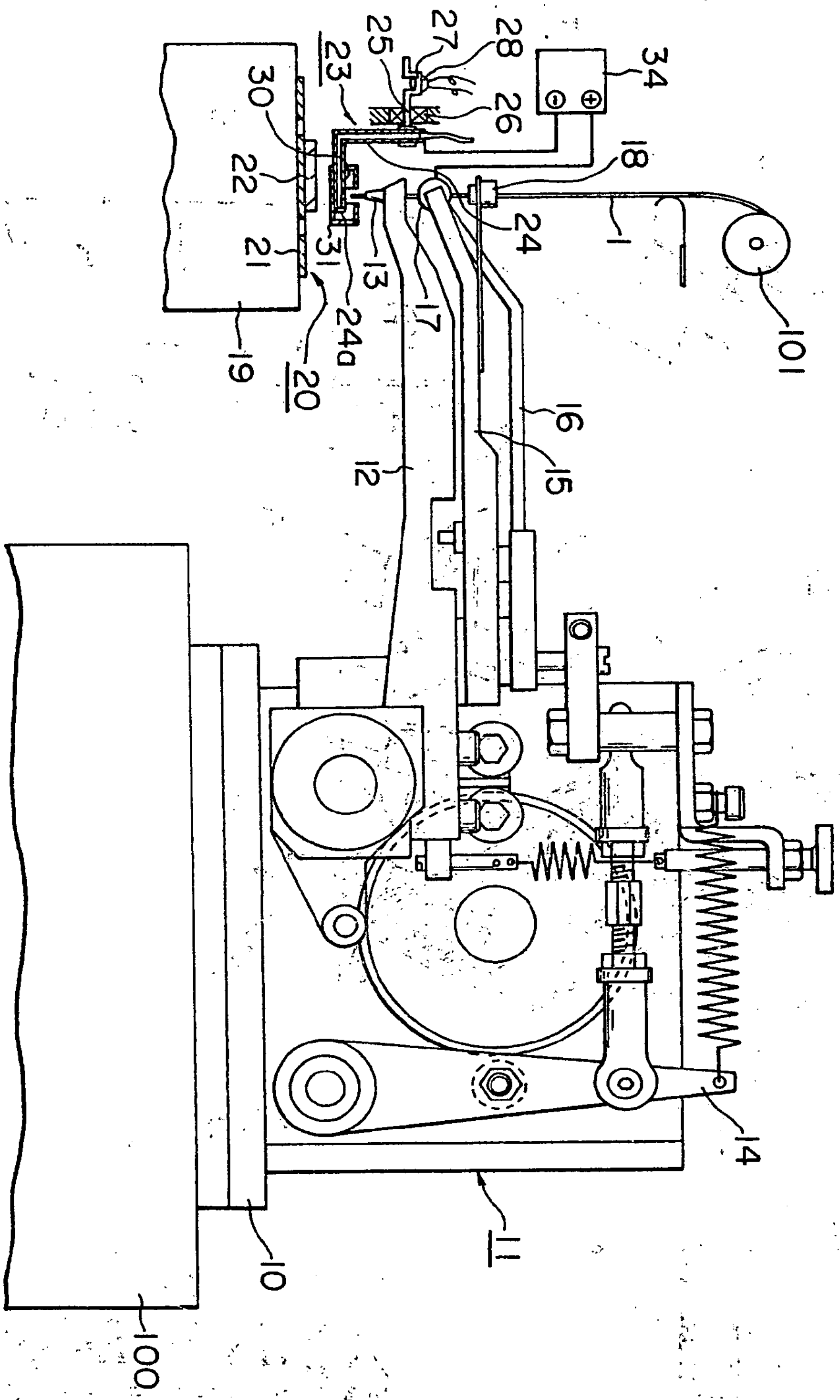


FIG. 1

FIG. 2

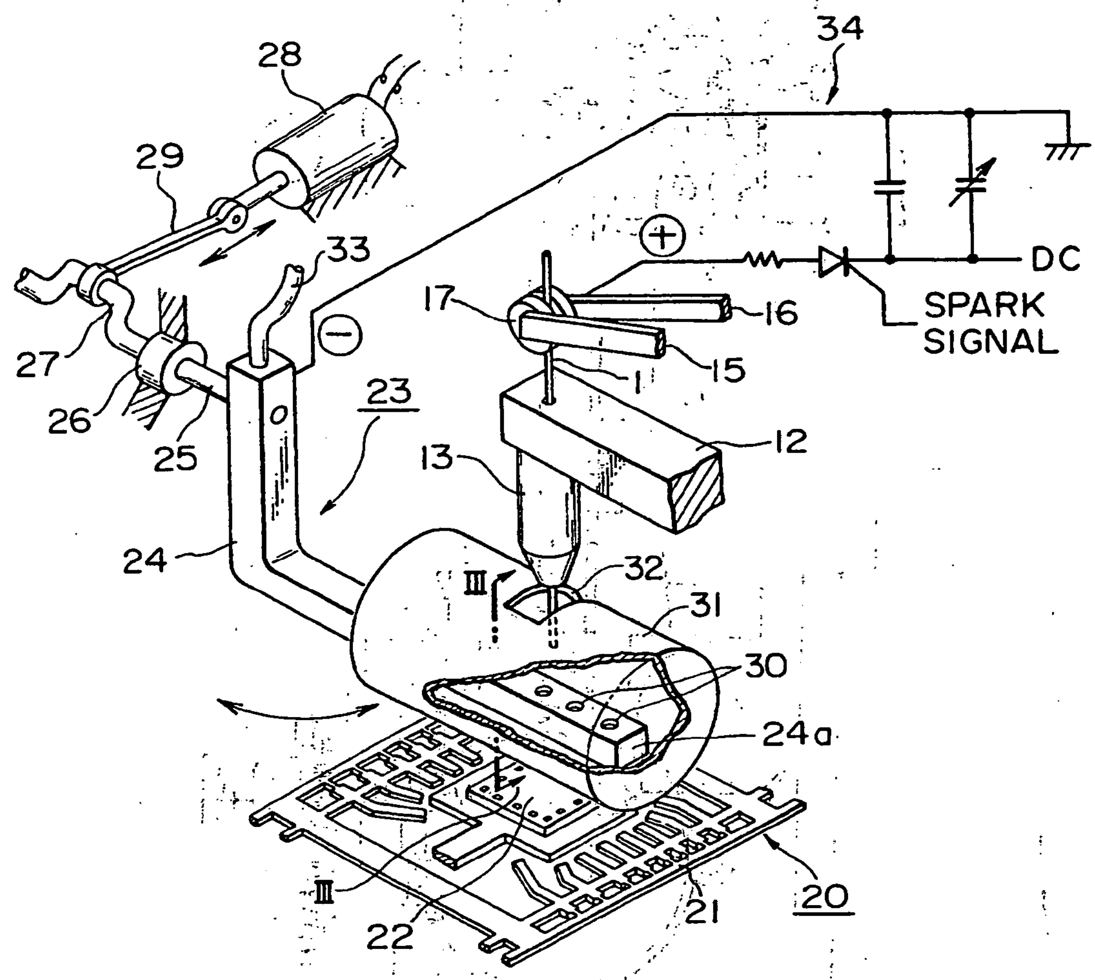


FIG. 3

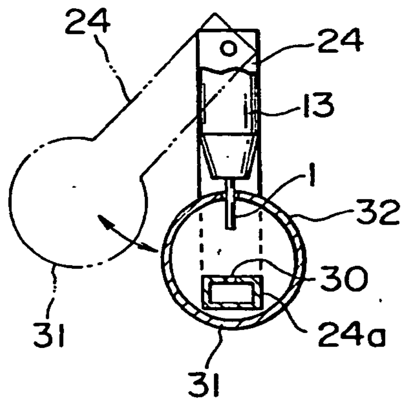


FIG. 4

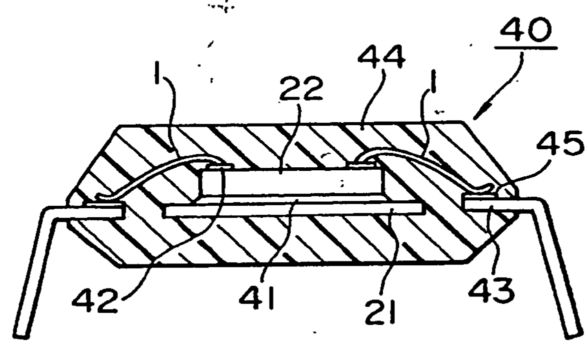


FIG. 5

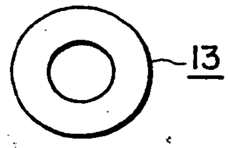


FIG. 6

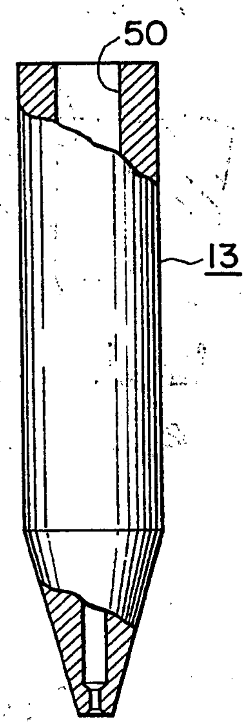


FIG. 7

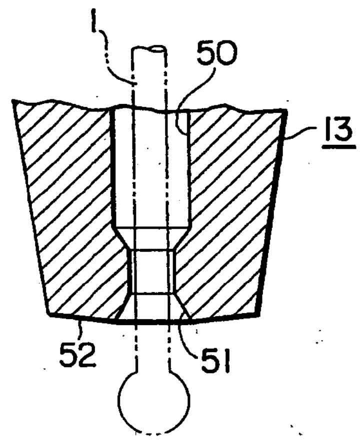


FIG. 8

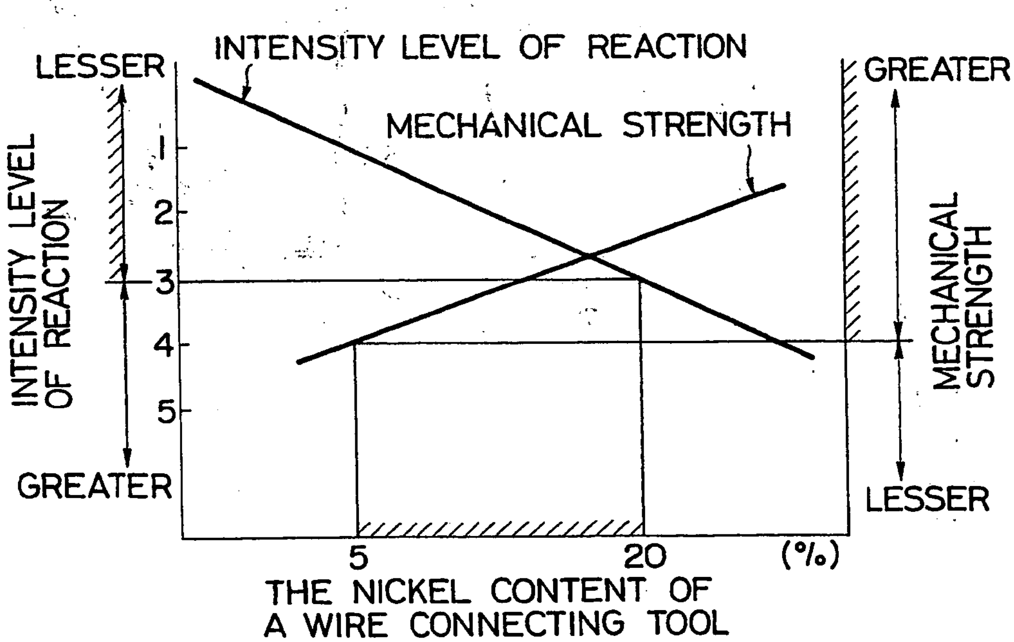


FIG. 9

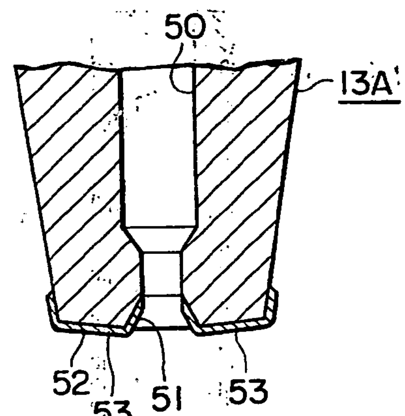


FIG. 10

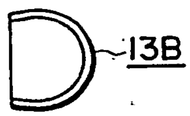


FIG. 11

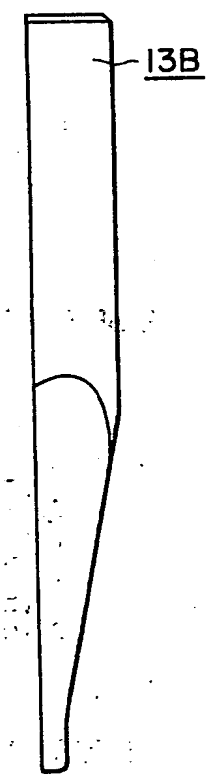


FIG. 12

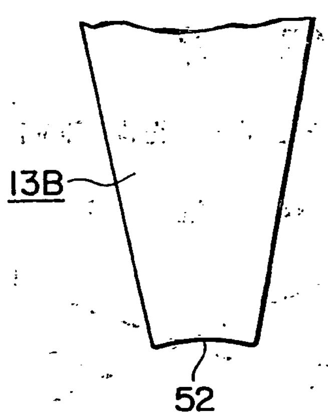
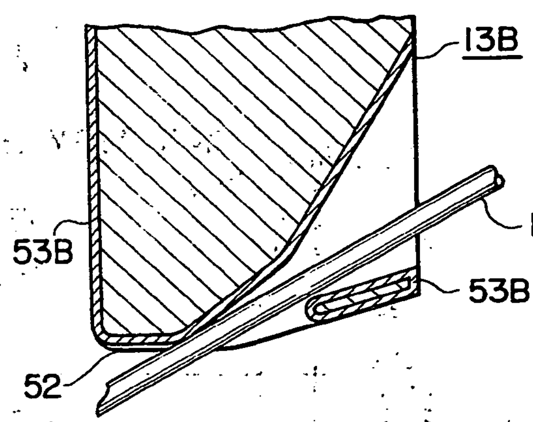


FIG. 13



SPECIFICATION

Method and apparatus for wire bonding

This invention relates to wire bonding techniques, and more particularly to a wire connecting tool and a wire bonding method and apparatus (wire bonder) using this wire connecting tool.

In a wire bonding operation which constitutes a step of manufacturing a semiconductor device, the inexpensive aluminum (Aℓ) has been used in recent years as a material for a bonding wire instead of the expensive gold (Au). Even in a wire bonding operation using this aluminum (Aℓ) bonding wire, the employment of the so-called ultrasonic wire bonding techniques tends to be superseded by the nailhead thermocompression wire bonding techniques in order that the bonding operation can be carried out easily. Various types of wire bonding systems, in which a conventional wire bonder for a Au wire is utilized substantially as it is to bond an inexpensive Aℓ bonding wire instead of an expensive Au bonding wire, have been put to use for trial. It has been ascertained by the inventors of this invention that these bonding systems are incapable of obtaining a high bondability since the Aℓ bonding wire sticks to the bonding tool (apparatus), i.e. a capillary constituting a thermocompression wire bonding tool.

The wire bonding techniques referred to above will now be described more in detail as follows.

The steps of manufacturing a semiconductor device include a wire bonding step in which an electrode pad of a semiconductor element pellet and a lead constituting its external conductor member are connected together electrically by a wire. The wire bonding methods utilized widely at present include a thermocompression wire bonding method using a capillary as a wire connecting tool and a gold (Au) wire as a bonding wire, and an ultrasonic wire bonding method using a wedge as a wire connecting tool and an aluminum (Aℓ) wire as a bonding wire. The thermocompression wire bonding method using an Au wire is a so-called nailhead bonding method, in which the tip of a wire of Au, an oxidation-resisting metal is melted thermally with a hydrogen torch or a discharge arc to form a gold ball, which is then fastened under pressure to a bonding portion by using a capillary (wire connecting tool). This wire bonding method enables a bonding wire to be fastened to an object portion firmly, and is advantageous in that it has no wire bonding directivity. However, when a bonding portion consists of a pellet electrode pad composed of an aluminum material, a purple plague phenomenon (a phenomenon occurring when Au-Aℓ is heated to not lower than 300°C to form a purple chemical compound of $AuA\ell_2$) occurs to cause the bonding strength to decrease. In addition, the gold is expensive, and, when the price of the gold increases, the wire bonding cost also increases. On the other hand, in the ultrasonic wire bonding method using an Aℓ wire, the Aℓ wire is fastened to a bonding portion by the ultrasonic vibrations with a wedge (wire connecting tool). Since the aluminum wire is inexpensive, the wire bonding cost becomes low. However, the bonding directivity occurs since the wire bonding is done by the ultrasonic vibrations. This causes the construction of the wire bonder, a wire bonding apparatus, to become complicated. The bonding speed in the ultrasonic wire bonding method is low as compared with that in the thermocompression wire bonding method.

Therefore, in recent years, a wire bonding method making the most of both the thermocompression wire bonding method and the ultrasonic wire bonding method and using a simply-constructed wire bonding apparatus of a thermocompression system, which employs a bonding wire of Aℓ, a low-priced bonding wire material, and which is capable of carrying out a wire bonding operation with no directivity and at a high speed, i.e. a wire bonding method in which a ball is formed at the tip of an Aℓ wire to then subject the ball to the nailhead bonding, now attracts attention.

However, it has been ascertained by the inventors of the present invention that, in the ultrasonic wire bonding method and the thermocompression wire bonding method, in both of which an aluminum wire is used as a bonding wire, the aluminum wire sticks to a wire connecting tool called a capillary or a wedge to prevent a normal wire bonding operation from being carried out. Namely, it has been ascertained that the aluminum wire is bonded insufficiently to an object portion of a material to be wire bonded and comes off therefrom, or cannot be bonded at all.

As mentioned above, it has been discovered that these inconveniences occur even in an ultrasonic wire bonding operation using an aluminum wire, and that a noticeable wire bonding trouble occurs in a thermocompression wire bonding operation using an aluminum wire as a bonding wire.

Namely, in a thermocompression wire bonding operation using an aluminum wire, capillary, a wire connecting tool, and the aluminum wire are liable to stick to each other. Furthermore, when the aluminum wire is thermally compressed against a material to be wire-bonded by using a capillary, a wire connecting tool, the ultrasonic vibrations ar appli d a little to the capillary, i.e. the thermocompressive forc and the bonding force based on the ultrasonic vibrations are used together, so that the temperature of the wire bonding portion becomes high. Consequently, a physiochemical reaction occurs between the aluminum and capillary, and the aluminum wire sticks to the surface of the capillary. Especially, a problem in which the wire-inserting bore in the capillary is stopped up with the aluminum wire occurs in some cases. This pr vents the aluminum wire inserted into the bore in the capillary from being moved vertically therein, to cause a decrease in the efficiency of the bonding operation.

The capillary us d in a thermocompression type wire bonder using an aluminum wire consists of aluminum oxide (alumina) $A\ell_2O_3$, ruby, and a c rmet containing tungsten carbide WC or titanium carbid

TiC.

The alumina and ruby are the materials to which the aluminum Aℓ sticks easily. The TiC-containing cermet is a material to which Aℓ sticks only lightly. It has been ascertained that the xtent to which Aℓ sticks to a TiC-containing cermet varies depending upon the kind and content of the binder contained therein. It has been discovered that the causes from which Aℓ sticks to a TiC-containing cermet reside in the following. It is considered that a conventional capillary consisting of a TiC-containing cermet contains not less than 25% by weight, which is based on the total weight of the capillary, of nickel (Ni) as a binder, and that the nickel (Ni) in the capillary generates a fusion reaction with Aℓ which constitutes the Aℓ bonding wire. Moreover, since the capillary consisting of a TiC-containing cermet is a sinter, it has a rough surface in which Ni constituting a binder is exposed, this Ni further promoting the fusion reaction between the Ni and Aℓ wire.

An object of the present invention is to provide a wire bonding apparatus capable of preventing the fusion from occurring between a bonding wire and a wire connecting tool.

The present invention can provide a wire bonding apparatus capable of guiding freely with a wire connecting tool a bonding wire to a material to be wire bonded, and bonding the wire thereto with a high bondability.

The present invention can also provide a wire bonding method capable of bonding a wire to a material to be wire-bonded, by using a wire connecting tool with high accuracy and reliability.

The present invention can further provide a wire bonder capable of preventing the fusion of an Al wire and a capillary or a wedge to improve the bondability of the Al wire, and carrying out a wire bonding operation excellently without any insufficiently bonded portions.

Embodiments of the invention will be given in the following description in conjunction with the accompanying drawings.

Figure 1 is a front elevational view of an embodiment of a wire bonder according to the present invention;

Figure 2 is an enlarged perspective view of a principal portion of the wire bonder shown in Figure 1;

Figure 3 is a sectional view take along the arrows III-III in Figure 2;

Figure 4 is a sectional view of a semiconductor device formed by carrying out a wire bonding operation with the wire bonder shown in Figure 1;

Figure 5 is a top plan view of an example of a capillary used in the present invention;

Figure 6 is a partially cutaway view in front elevation of the capillary shown in Figure 5;

Figure 7 is an enlarged sectional view of a tip portion of the capillary shown in Figure 6;

Figure 8 is a graph used to determined the content of nickel (Ni) used as a binder in the TiC cermet which constitutes a wire connecting tool;

Figure 9 is an enlarged sectional view of a tip portion of another example of a capillary used in the present invention;

Figure 10 is a top plan view of a wedge, still another example of the wire connecting tool used in the present invention;

Figure 11 is a front elevational view of the wedge shown in Figure 10;

Figure 12 is an enlarged left side elevational view of a tip portion of the wedge shown in Figure 11; and

Figure 13 is an enlarged sectional view of the tip portion of the wedge shown in Figure 11.

Figure 1 is a front elevational view of an embodiment of a wire bonder according to the present invention. Referring to Figure 1, a bonding arm 12 is supported pivotally at its base end on a bonding head 11 which is mounted on an XY table 10 placed on a base 100 of the wire bonder. Thus, a tip portion, to which a capillary 13, a wire connecting tool, is fixed, of the bonding arm 12 can be moved pivotally in the vertical direction by a cam mechanism. A pair of clamper arms 15, 16 actuated by a cam driving member 14 or an electromagnetic solenoid are provided above the bonding arm 12 so that the tip portions of these arms 15, 16 are positioned immediately above the capillary 13 to form a clamper 17. Reference numeral 1 denotes an Aℓ wire used as a bonding wire. The Aℓ wire is payed out from a spool 101 to be inserted through a guide 18 and then into the capillary 13 through the clamper 17. The wire is not limited to an Aℓ wire; it may be a wire consisting of an easily oxidizable metal, such as aluminum alloys including aluminum containing a small amount of silicon (Si), and aluminum containing a small amount of nickel (Ni).

On the other hand, reference numeral 19 denotes a bonding stage, on which a lead frame 20 with a semiconductor element pellet, a material to be wire-bonded, bonded to the upper surface thereof, is placed. The Aℓ wire 1 is c nnected between th lead frame 21 and semiconductor element pellet 22 as the capillary 13 is moved up and down.

Reference numeral 23 denotes a discharge electrode portion consisting of an electric conductor and provided independently in the proximity of the capillary 13. As shown in b th Figure 2 and Figure 3, th discharge electrode portion 23 has a substantially L-shaped hollow electrode 24. A pivot 25 connected unitarily to an upper end portion of the electrode 24 is supported pivotably on a bearing 26 in a wire bonder fixing portion, as that the electrode 24 as a whole can be moved reciprocatingly in the horizontal direction, i.e. turned in the direction of a dual arrow in Figure 3. Accordingly, a lower portion 24a of the electrode 24 can be moved below the capillary 13, i.e. between a positive immediately below the tip of

the the Aℓ wire 1 and a sideway position (retreating position) of the capillary 13. In this case, if a crank 27 is formed at a part of the pivot 25 and connected to an additionally-provided electromagnetic solenoid 28 by a connecting rod 29, the reciprocating movement of the solenoid 28 can be changed into the reciprocating arcuate movement of the electrode 24 described above. A plurality of through holes are made in the upper wall of the lower portion 24a of the electrode 24 so as to communicate with the inner hollow of the electrode, and a cylindrical cover 31 is fitted around the lower portion 24a so as to encompass the same. The cover 31 is provided at its upper portion with a slot 32 extending over substantially one quarter of the circumference thereof, so as to enable, when the electrode 24 moves down, the tip of the Aℓ wire 1 to penetrate into the cover through the slot 32. A tube 33 communicating with the inner hollow of the electrode 24 is provided at the base end thereof, through which tube 33 a gas, which will be described later, is supplied into the electrode 24. A power source circuit 23 shown in Figure 2 is connected between the electrode 24 and the clamper 17 so that the clamper 17, i.e. the Aℓ wire 1 connected thereto serves as the positive plate with the electrode 24 serving as the negative plate. A discharge arc is generated from the electrode 24 toward the Aℓ wire 1.

This embodiment uses a reducing gas as the gas mentioned previously, which is prepared by diluting, for example, hydrogen (H_2), carbon monoxide (CO), dinitrogen oxide (N_2O) or methane (CH_4) with an inert gas (argon or nitrogen gas). The gas is injected into the cover 31 from the through holes 30 in the side portion 24a of the electrode 24 so as to keep the interior of the cover 31, i.e. the space between the electrode 24 and Aℓ wire 1 in a reducing gas atmosphere.

According to the above-described construction, when the electromagnetic solenoid 28 is energized, so that the shaft thereof extends and contracts to cause the crank 27 and pivot 25 to swing, the side portion 24a of the electrode 24 turns downward to be positioned immediately below the Aℓ wire 1, thereby causing the tip portion of the Aℓ wire to penetrate into the cover 31. The interior of the cover 31, i.e. the space between the Aℓ wire 1 and electrode 24 is then held in the reducing gas atmosphere by the reducing gas injected from a plurality of through holes 30 via the inner hollow of the electrode 24. When the power source circuit 34 is then turned on, a discharge arc is generated between the Aℓ wire 1 and electrode 24, and the free end of the Aℓ wire is fused by the arc energy to form a ball. Since the ball formation of the Aℓ wire 1 in this embodiment is effected in a reducing gas atmosphere, the alumina, an oxide of aluminium on the surface of the aluminium (Aℓ) wire is reduced to aluminium. Since the fusing is effected under such condition, both the inside and surface of the tip of the Aℓ wire are fused uniformly as a whole. For this reason, a uniform surface tension occurs, and a ball having a high sphericity is formed.

In this embodiment, the Aℓ wire as the bonding wire is used as the positive plate, and the discharge electrode as the negative plate. Accordingly, the discharge arc in this instance is generated from the electrode 24 toward the Aℓ wire 1 due to the polarities thereof. Hence, a so-called "cleaning phenomenon" (in which the arc travels while searching for the fresh oxide film on the Aℓ wire surface and occurs from the Aℓ wire tip over a wide range in the proximity of the tip) does not occur, so that the terminal influence is not exerted on the portions other than the ball-forming portion of the Aℓ wire; only the free end of the aluminium wire is locally heat-fused to form the Aℓ ball having a high sphericity. Moreover, owing to this local heating phenomenon, no constriction is formed at the portion of the Aℓ wire which is immediately above the ball.

After the ball is formed, the pivot 25 and electrode 24 are turned upward by the operation of the electromagnetic solenoid 28 and the retracting operation of its shaft, and the side portion 24a of the electrode is moved back from the position immediately below the Aℓ wire 1. Accordingly, when the capillary 13 is moved down with the swinging of the bonding arm 12, the Aℓ wire 1 can be thermo-compression bonded to the pellet 22 on the member 20 to be wire-bonded. Since the ball thus formed has a high sphericity, the wire bonding can be effected with a high reliability.

Another embodiment of the present invention will now be described. This embodiment is characterized in that an inert gas to which a gas having the thermal pinch operation is added is used as the gas to be supplied into the electrode 24 in addition to the reducing gas used in the first embodiment. The examples of the gas having such a thermal pinch operation are hydrogen (H_2), helium (He), methane (CH_4), nitrogen (N_2) and carbon monoxide (CO). If this gas is present in the atmosphere between the Aℓ wire 1 and the electrode 24, a so-called thermal pinch action is obtained in which the discharge arc concentrates upon the tip of the Aℓ wire, so that the discharge energy concentrates thereupon. Thus, the discharge energy is used effectively for the formation of the ball to thereby improve the sphericity of the ball and accomplish the n rgy saving. This thermal pinch action occur irrespectiv of the polarity of the power source to be applied to th Aℓ wir , i.e. wh th r or n t th polarity is positive or negative. Th refore, the power source circuit 34 is not limited to th one shown in Figure 2. If hydrogen (H_2), methane (CH_4) or carbon monoxide (CO), each of which has both a reducing action and a thermal pinch action, is used as the gas, the single gas provides both actions and their effects.

An example of the semiconductor device thus formed is shown in Figure 4. In this semiconductor device 40, the pellet 22 is fixed on the lead frame 21 by a Au-Si eutectic crystal 41, and the pad 42 of the pellet 22 and the inner lead 43 of the lead frame 21 are then connected to each other by the Aℓ wire 1. The resultant product is thereafter mould-sealed by using a resin 44. The Aℓ wire 1 is thermo-compression bonded after the ball is formed in the mann r described above. In this case, it is possible t use an

aluminium alloy material consisting principally of aluminium and containing about 1% by weight of silicon (Si) or an aluminium alloy consisting principally of aluminium and containing about 0.5% by weight of nickel (Ni) in place of the aluminium wire 1.

The capillary 13, i.e. the wire bonding apparatus (wire connecting tool) in the thermo-compression wire bonder is constructed as shown in Figure 5 which is a top plan view thereof, Figure 6 which is a partially cutaway view in front elevation thereof, and Figure 7 which is an enlarged section of the free end portion thereof.

The capillary 13 has as best seen from Figure 7 which illustrates the free end portion thereof on a larger scale conical chamfered portion 51 around the lower opening of an insert bore 50 for the $A\ell$ wire 1, and an upper portion of the insert bore 50 which has an inner diameter slightly larger than that of the free end portion thereof. The free end surface 52 is not flat but inclined slightly toward its circumferential portion. The capillary 13 consists of a cermet composed mainly of titanium carbide (TiC) and containing an iron group metal as a binder. Since this cermet has a comparatively high processability, it is suitably used to manufacture a capillary having the above-mentioned complicated shape. As is clear from Table 1 in which the properties of TiC are compared with those of some other carbides, TiC has a low reactivity with $A\ell$. The rating values shown in Table 1 were determined on the basis of the result of reactions between various kinds of carbides and a molten aluminium, which reactions were conducted by immersing these carbides in molten aluminium-containing vessels for 60 minutes. A larger rating value shows a higher reactivity of the carbide with $A\ell$. Moreover, TiC has sufficiently high strength which is required by the capillary.

TABLE 1

Material	*Reaction with $A\ell$*	*Rating value*
TiC	Reacts a little.	2
ZrC	Reacts considerably.	4
Cr_3C_2	Reacts actively.	5
Mo_2C	Reacts actively.	5
WC	Reacts actively.	5

A cermet is a heat-resisting material obtained by compression-molding a mixture of ceramic powder and metal powder, and sintering the molded product. It was developed as a material having both the thermal resistance of a ceramic material and a high rigidity of a metal. The examples of the metal are Fe, Ni, Co, Cr and Cu, and the examples of the ceramic material are various oxides ($A\ell_2O_3$, BeO, ZrO_2 and ThO_2), carbides (TiC, Zrc, B_4C and WC) and borides (CrB and ZrB_2). The examples of combination of these materials include $A\ell_2O_3$-Fe, TiC-Ni, TiC-Co and B_4C-Fe.

On the other hand, nickel (Ni) is used effectively for the binder to be contained in TiC in a TiC cermet as the material of the wire connecting tool. The inventors of the present invention varied the content (wt%) of this binder experimentarily to determine the advance of anyone else the characteristics shown in Figure 8 of the wire connection tool. The reaction rating values shown in Figure 8 are the same as those shown in Table 1. It is understood from Figure 8 that, when the content of nickel (Ni) is increased, the strength of the wire connecting tool is improved with the possibility that the connecting wire reacts with (sticks to) $A\ell$, which constitutes a bonding wire, increasing, and that, conversely, when the content of nickel (Ni) in the capillary is reduced, the reactivity of the capillary with the $A\ell$ wire as a bonding wire decreases with the mechanical strength of the capillary as a wire connecting tool decreasing. Therefore, the nickel content is set preferably to 5-20% by weight and optimal to 5-15% by weight in order to obtain a capillary having a high mechanical strength and a low reactivity with respect to $A\ell$. In the experiments conducted by the inventors, some other kinds of binders containing molybdenum carbide (Mo_2C) were used. The results of various experiments show that the molybdenum carbide-containing binders having, for example, the following composition have excellent effects. The numeral values shown below represent weight percentages.

(1) TiC: Mo_2C : Ni = 70 : 15 : 15
(2) TiC : Mo_2C : Ni = 60 : 20 : 20
(3) TiC : Mo_2C : Ni = 76 : 12 : 12

Since the titanium carbide (TiC) and nickel (Ni) as a bind r are not combined with each other directly, the molybdenum carbide is used as a mediator for combining the titanium carbide (TiC) with nickel (Ni). Namely, the molybdenum carbide (Mo_2C) and titanium carbide (TiC) are combined with each other excellently, and the molybdenum carbide (Mo_2C) and nickel (Ni) are also combined with each ther excellently. Therefore, molybdenum carbide (Mo_2C) is laid on titanium carbide (TiC) so that the surfaces of particles of the latter are covered thoroughly with the former. Namely, the whole surfaces of the particles

of titanium carbide (TiC) are covered with molybdenum carbide (Mo_2C) to combine them together unitarily. The nickel (Ni) is then combined with the molybdenum carbide (Mo_2C) in the molybdenum carbide-coated titanium carbide (TiC) to thereby combine the molybdenum carbide-coated titanium carbide with nickel (Ni).

The material which constitutes the capillary, a wire connecting tool used in the present invention described carbide (TiC) and containing as a binder 5-15% by weight, which is based on the total weight of the capillary, of nickel (Ni). The TiC cermet has a rough surface peculiar to a sintered product, particles of nickel (Ni) among those of titanium carbide, and the nickel (Ni) is exposed at some portions of the surface of the capillary of TiC cermet. However, only a small quantity of nickel (Ni) is exposed in the region of the surface of the capillary which is to contact the aluminium ($A\ell$) wire used as a bonding wire. Such a small quantity of nickel causes no physico-chemical reactions to occur between the nickel (Ni) in the inside of the capillary and the $A\ell$ in the $A\ell$ wire. Accordingly, the $A\ell$ wire is not fused to the capillary consisting of a TiC cermet. Therefore, when the capillary in the present invention is used, the $A\ell$ wire as a bonding wire is not fused thereto, so that the bondability of the bonding apparatus does not decrease at all.

Figure 9 shows another embodiment of the present invention, especially, a principal portion of a capillary 13A. In this embodiment, the free end surface 52 and the surface of the chamfered portion 51 of the capillary 13 in the first embodiment are coated with a film 53 of silicon nitride (SiN). This film 53 is formed by a Chemical Vapor Deposition (CVD) method. It may be formed at least on the portion of the capillary which contacts the $A\ell$ wire 1. It may also be formed on the whole surface of the capillary 13A when there are certain processing reasons. The film formed by the CVD method has a smooth outer surface. If a silicon nitride (SiN) film 53 is this formed on the free end portion of the capillary, the possibility that the $A\ell$ wire sticks to the capillary decreases to a greater extent since the reactivity of SiN and $A\ell$ with respect to each other is low (the rating value, which is referred to previously, of the reactivity of SiN and $A\ell$ is 1). The film 53 covers the comparatively rough surface of the TiC cermet (sintered product) to form a smooth surface. Moreover, it completely covers the nickel (Ni) exposed in the TiC cermet surface. Accordingly, the sticking of the $A\ell$ wire to the capillary can be prevented more effectively. A SiN film having a thickness of not more than 0.1 μm has no satisfactory effect, and a SiN film having a thickness of not less than 10 μm comes off easily. The coating material may consist of any of the carbides of elements in IV, V and VI groups in the Periodic Table, such as TiC and ZrC, or a nitride, such as BN, in addition to SiN.

By way of experiment, 70% by weight of TiC powder, 1% by weight of Mo_2C powder and 15% by weight of Ni powder were mixed in a ball mill, and the resultant mixture was subjected to the dry pressure molding, the molded product being then sintered under vacuum at 1400°C for 1 hour. The sintered product was processed to form a capillary. The titanium carbide (TiC) was applied to the capillary to a coat of 2 μm by the CVD (chemical vapor deposition) method. A wire bonding test was conducted by using this capillary with an $A\ell$ wire having a diameter of 30 - 50 μm. As a result, $A\ell$ did not stick to the capillary even after the wire bonding was done more than 100000 times, unlike the case where a conventional capillary consisting of alumina is used, in which case $A\ell$ sticks to the capillary after the wire bonding is done only 2000 - 20000 times.

What is shown in Figures 10 - 13 is a wedge, i.e. a wire connecting tool used for an ultrasonic wire bonder, this wedge being used in the wire bonding techniques comprising still another embodiment of the present invention. Figure 10 is a top plan view of the wedge, Figure 11 a front elevational view of the wedge, Figure 12 an enlarged left side elevation of the free end portion of the wedge, and Figure 13 an enlarged section of the free portion end portion of the wedge. A body of the wedge 13B is formed in the shape of a wedge as shown in the drawings, and the material thereof is tungsten carbide (WC) or titanium carbide (TiC). The free end surface of the wedge 13B is flat or concave.

The free end portion of the wedge 13B is covered with a titanium carbide (TiC) film 53B by using the ion plating techniques. This titanium carbide (TiC) film 53B may alternatively be formed by the CVD method. The ion plating method is capable of forming a TiC film at a lower temperature than the CVD method; the former method enables a TiC film to be formed without thermally deforming the wedge body. It is clear that the TiC film on the previously-mentioned capillary 13 can also be formed by the ion plating method.

The ion plating method includes a direct current method, a high-frequency method, a cluster ion beam method and a hot cathode method. These methods are identical in that the vapor generated to form a film is ioniz d during the formation f the film, resultant film containing ions accelerated toward the substrate.

In the high-frequency method, a high-frequency coil is provided between a substrate, which is used in the direct current method, and a vapor source to enable the electric discharge to be held under a pressure of not more than 10^{-3} Torr, i.e. the ion plating is done under high vacuum. In the high-frequency method, a reaction in plasma can also be utilized to form a film of this kind.

In the cluster ion beam method, a material is evaporated in a crucible having a small hole, to increase the pressure therein to a comparatively high level, so that the evaporated material is ejected from the small hole in the form of a lump (called "cluster") of about 10^3 atoms. The cluster is ionized in a subsequ nt chamber by using an ionizing grid and a hot cathode, and the ions are smashed in an accelerated

state against a substrate, which is set to the negative electric potential, to form a film. In the hot cathode method, the vapor is not made in the form of cluster. In this meth d, the ion plating is done under high vacuum according to the principle which is substantially the same as that of th cluster ion beam evaporation.

The ion plating method has a good influence upon the crystallization of a film. It is considered that the reasons why the ion plating method is capable of obtaining a film having a high crystallinity are as follows. Due to the impact of the high-energy ions, the temperature of the surface of the substrate increases (to 100°C - 300°C). Due to the impact of the ions, many flaws occur on the substrate surface, and the crystallization proceeds thereabound. The possibility of crystallization by the charge of ions is higher than that by neutral particles. Although the ions lose the electric charge before they impinge upon the substrate, they have high energy even after they enter the substrate. Accordingly, the ions can move easily in the surface of the substrate, so that crystals can be formed easily.

When the ion plating method is used, a film having a high bond strength can be formed at a temperature lower than that in the CVD method. Moreover, the particles of a material to be covered with a film are displaced favorably, so that a film can be formed in an excellent step covering manner on various types of objects including an object having a rough surface and an object having a complicated shape like a capillary and a wedge.

A SiN film or a TiC film can be formed on the free end portion of a capillary, a wire connecting tool used for a thermo-compression wire bonder, and a wedge, a wire connecting tool used for an ultrasonic wire bonder, at a lower temperature by the ion plating method than by the CVD method. Accordingly, when a film is formed by the ion plating method, no thermal deformation occurs in the wire connecting tool, so that a wire connecting tool having a high accuracy can be formed.

The various effects of the wire bonding apparatus according to the present invention may be understood clearly from the above statement. The present invention can have further effects which are as follows.

(1) The wire connecting tool may consist of a capillary is made of titanium carbide (TiC) containing 5 - 15% by weight of nickel (Ni) as a binder. Accordingly, the wire connecting tool consisting of a capillary can secure its required level of strength, and has a reduced reactivity with respect to an $A\ell$ wire. Therefore, the sticking of an $A\ell$ wire to the wire connecting tool consisting of a capillary can be prevented, and the bondability of the wire bonding apparatus can be improved, so that an insufficient wire bonding operation can be virtually prevented.

(2) A SiN film or a TiC film can be formed on the surface of the wire connecting tool consisting of a capillary composed mainly of TiC. Owing to the low reactivity of the film material with respect to the aluminium ($A\ell$) wire, which is used as a bonding wire, and the smooth surface of the film, the sticking of the $A\ell$ wire to the wire connecting tool can be prevented more effectively.

(3) A film, such as a TiC film, which does not generate a physicochemical reaction with aluminium ($A\ell$), may be formed on at least the portion of a capillary, a wire connecting tool used in the thermo-compression wire bonding, or a wedge, a wire connecting tool used in the ultrasonic wire bonding, which contacts a bonding wire. Accordingly, the aluminium ($A\ell$) wire used as a bonding wire does not stick, when it is fused, to the wire connecting tool provided with such a bonding wire sticking-preventing film thereon. Therefore, the aluminium ($A\ell$) wire, which is guided by the wire connecting tool to be bonded to an object material, does not cause any decreased in the bondability of the wire bonding apparatus in operation, so that a wire bonding operation can be carried out with a high accuracy and a high reliability.

The preferable examples of the material for the bonding wire sticking-preventing film are silicon nitride (SiN), titanium carbide (TiC), zirconium carbide (ZrC), carbides of the elements in IV group in the Periodic Table, or carbides of the elements in V group therein, or carbides of the elements in VI group therein and nitrides, such as boron nitride (BN).

The specially effective methods of forming such a film are the chemical vapor deposition (CVD) method, and the ion plating method which is capable of forming the film at which a temperature lower than the temperature at which the CVD method is carried out. However, the film can also be formed by using various other film-forming techniques.

The capillary body or the wedge body, which constitutes a wire connecting tool on which the film is to be formed, can be molded out of tungsten carbide (WC), tantalum carbide (TaC), titanium carbide (TiC), alumina, single crystal of sapphire, and ruby, i.e. molten alumina. The wire connecting tools consisting of these materials and having various shapes can be used.

(4) A wire bonding apparatus using a wire connecting tool according to the present invention is capabl of feeding a bonding wire smoothly without being stuck to the wire connecting tool, during a wire bonding op ration in a semiconductor device assembling step. Accordingly, the wire bonding can be done normally. Nam ly, the wire bonding can be done without hurting a member to be wire-bonded, without causing an unsatisfactorily wire-bonded semiconductor d vice to be produced, and with a high accuracy, a high reliability and a high work efficiency.

(5) In the wire bonding method using the wire connecting tool according to the present invention, the bonding wire is not fused to the wire bonding tool. Therefore, the wire connecting tool is not stopped up with the bonding wire. Namely, the bonding wire is fed normally. As a result, a wire bonding operation under an abnormal pressure can be avoided. Moreover, the wire bonding can be done with a suitable

length of bonding wire. Accordingly, the bondability of the wire bonding apparatus can be improved greatly, and the wire bonding operation can be carried out with a high efficiency.

(6) Since the sticking of Aℓ wire to the wire connecting tool can be prevented to improve the bondability of the wire bonding apparatus, the reduction of the cost of carrying out a wire bonding operation with an Aℓ wire and the increasing of the wire bonding speed can be attained, and the reliability of a wire bonding operation can be improved.

The invention achieved by the inventors of the present invention has been described concretely on the basis of the embodiment thereof. It is needless to say that the present invention is not limited to the above-described embodiments, and that the invention can be modified in various ways without departing the gist thereof. For example, the shape of the capillary can be changed arbitrarily. Any suitable method other than the CVD method and the ion plating method may be used to form a film on the wire connecting tool.

The above description refers mainly to the wire bonding technique using an Aℓ wire, which are applied to a semiconductor device belonging to the field in which the present invention is utilized. However, the article to which the present invention is applied is not limited to a semiconductor device. The present invention can be applied very effectively to various types of conventional wire bonding apparatuses, such as a wedge bonding apparatus. The wire bonding apparatus according to the present invention can be applied to all kinds of electronic parts to which an Aℓ wire is connected.

CLAIMS

1. A wire bonding method, wherein a plurality of first wire bonding regions of a member to be wire-bonded and a plurality of second wire bonding regions thereof which are opposed to said first wire bonding regions are connected together by a bonding wire which consists mainly of aluminium (Aℓ), characterized in that a wire connecting tool used for connecting together by said bonding wire said first and second wire bonding regions of said member to be wire-bonded consists at at least the region thereof which contacts said bonding wire of a material which does not easily generate a physicochemical reaction with the aluminium (Aℓ).

2. A wire bonding apparatus having a wire connecting tool for guiding a bonding wire to a member to be wire-bonded and bonding said wire to said member, an elongated bar type bonding arm to one end of which said wire connecting tool is fixed, a driving mechanism connected mechanically to said bonding arm and adapted to swing the same vertically, and an XY table provided thereon with said bonding arm and capable of moving the same longitudinally and laterally in the horizontal direction, characterized in that said wire connecting tool consists at at least the region thereof which contacts said bonding wire of a material which does not easily generate a physicochemical reaction therewith.

3. A wire bonding apparatus according to Claim 2, wherein said wire connecting tool is a capillary for carrying out a thermo-compression wire bonding operation.

4. A wire bonding apparatus according to Claim 2, wherein said wire connecting tool is a capillary for carrying out a thermo-compression wire bonding operation, an ultrasonic osciallation generating source being connected to said bonding arm, said ultrasonic osciallation generating source being capable of applying ultrasonic oscillation to said capillary at the suitable time.

5. A wire bonding apparatus according to Claim 2, wherein said wire connecting tool is a wedge for carrying out an ultrasonic wire bonding operation.

6. A wire bonding apparatus to any one of claims 2 to 5, wherein said bonding wire is an aluminium (Aℓ) wire, or a wire consisting of a an alloy composed mainly of aluminium, such as aluminium containing a small quantity of silicon (Si), and aluminium containing a small quantity of nickel (Ni).

7. A wire bonding apparatus according to any one of claims 2 to 6, wherein said wire connecting tool is molded out of a cermet of titanium carbide (TiC) which contains 5 - 15% by weight of nickel (Ni) as a binder.

8. A wire bonding apparatus according to any one of claims 2 to 7, wherein said wire connecting tool is covered at at least the region of a wire connecting tool body which contacts said bonding wire with a film consisting of a material which does not easily cause said bonding wire to react physicochemically with the surface of said wire connecting tool.

9. A wire bonding tool fixed to a free end portion of a bonding arm in a wire bonding apparatus and adapted to guide a bonding wire to a member to be wire-bonded and bond said wire to said member, characterized in that at least the regi n of said wir bonding tool which contacts said bonding wire consists f a material which does not easily generate a phisicochemical reaction with said bonding wire.

10. A wire bonding tool according to Claim 9, wherein said bonding wire is an aluminium (Aℓ) wire or a wire consisting of an alloy composed mainly of aluminium, such as aluminium containing a small quantity of silicon (Si), and aluminium containing a small quantity of nickel (Ni).

11. A wire bonding tool according to claim 9 or claim 10, wherein said wire connecting tool is a capillary for carrying out a thermo-compression wire bonding operation, said capillary being provided with a through bore extending in the axial direction thereof and adapted to insert said bonding wire therethrough.

12. A wire bonding tool according to claim 9 or claim 10 wherein said wir conn cting tool is a capil-

lary for carrying out a thermo-compression wir bonding operation with the ultrasonic oscillation applied thereto, said capillary being provided with a through bore extending in the axial direction thereof and adapted to insert said bonding wire th rethrough.

13. A wire bonding tool according to claim 9 or claim 10 wherein said wire connecting tool is a wedge for carrying out an ultrasonic wire bonding operation.

14. A wire bonding tool according to any one of claims 9 to 13 wherein said wire connecting tool is molded out of a cermet of titanium carbide (TiC) containing 5 - 15% by weight of nickel (Ni) as a binder.

15. A wire bonding tool according to any one of claims 9 to 13 wherein a body of said wire connecting tool is molded out of a cermet of titanium carbide (TiC) containing 5 - 15% by weight of nickel (Ni) as a binder, at least the region of said wire connecting tool body which contacts said bonding wire is covered with a film consisting of a material which does not easily cause said bonding wire to react physicochemically with the surface of said wire connecting tool.

16. A wire bonding tool according to any one of claims 9 to 13 wherein said wire connecting tool is covered at at least the region of a body thereof which contacts said bonding wire with a film consisting of a material which does not easily cause said bonding wire to react physicochemically with the surface of said wire connecting tool.

17. A wire bonding tool according to any one of claims 9 to 13 wherein said wire connecting tool is covered at at least the region of a body thereof which contacts said bonding wire with a film consisting of a carbide or a nitride of an element in IV group, V group and VI group in the Periodic Table, such as titanium carbide (TiC), tantalum carbide (TaC), zirconium carbide (ZrC), silicon nitride (SiN) and boron nitride (BN), said film being formed by the chemical vapor deposition method or the ion plating method.

18. A wire bonding tool according to Claim 17, wherein the thickness of said film formed on said wire connecting tool is 0.1 - 10 μm.

19. A wire bonding tool according to claim 17 or claim 18 wherein the material of said wire connecting tool body is a material consisting mainly of titanium carbide (TiC) or tungsten carbide (WC) or tantalum carbide (TaC), or alumina ceramic, sapphire or ruby.

20. A wire bonding tool according to Claim 9, wherein a body of said wire connecting tool consists of one of titanium carbide (TiC) cermet, tungsten carbide (WC) cermet, tantalum carbide (TaC) cermet, alumina ceramic, sapphire and ruby, said film, with which at least the region of said wire connecting tool body which contacts a wire used as said bonding wire and consisting mainly of aluminium (Aℓ) is covered, being composed of one of titanium carbide (TiC), tantalum carbide (TaC), zirconium carbide (ZrC), silicon nitride (SiN) and boron nitride (BN) and formed by the chemical vapor deposition method or the ion plating method.

21. A method of wire bonding substantially as any herein described with reference to the accompanying drawings.

22. A wire bonding tool substantially as any herein described with reference to and as shown in the accompanying drawings.

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